Capacitive Acceleration Sensor

Field of the Invention

The present invention relates to measuring devices used in the measuring of acceleration, and specifically to capacitive acceleration sensors. An object of the invention is to provide an improved sensor structure, which enables reliable and efficient measuring of acceleration, in particular in small capacitive acceleration sensor designs.

Background of the Invention

Measuring based on a capacitive acceleration sensor has proved to have a simple principle and to provide a reliable method for the measuring of acceleration. The capacitive measuring is based on a change in the gap between two surfaces of a pair of electrodes of the sensor. The capacitance between the surfaces, i.e. the capacity for storing electric charge depends on the area of the surfaces and on the distance between the surfaces. Capacitive measuring can be used already at rather low measuring ranges of acceleration.

The prior art is described below with exemplifying reference to the accompanying figures, of which:
Figure 1 shows a perspective view of the structure of a pair of electrodes of an acceleration sensor according to prior art, and
Figure 2 shows a side view of the functional structure of a pair of electrodes, based on a translatory motion, of the acceleration sensor according to prior art.

Figure 1 shows a perspective view of the structure of a pair of electrodes of an acceleration sensor according to prior art. The pair of electrodes of the acceleration sensor according to prior art comprises a movable electrode 1, which moves according to the acceleration, and a stationary electrode 2. The movable electrode 1 is that part 1, which is responsive to the acceleration of the acceleration sensor, and which part, in consequence of the acceleration, moves in relation to the stationary electrode 2. The movable electrode 1 and the stationary electrode 2 constitute a pair of electrodes converting acceleration into a quantity that can be measured electrically, i.e. capacitance. In the figure, the movable electrode 1 of the acceleration sensor is supported at points 3 and 4. Generally, on the opposite side of the movable electrode 1, the acceleration sensor of prior art also comprises a second pair of electrodes, which is not shown in the Figure for clarity reasons.

The acceleration sensor can be implemented based on either a translatory motion or a rotational motion of the movable electrode of the pair of electrodes.

Figure 2 shows a side view of the functional structure of a pair of electrodes, based on a translatory motion of the acceleration sensor, according to prior art. The pair of electrodes of the acceleration sensor according to prior art comprises a movable electrode 1 and a stationary plate portion 2. The support point of the movable electrode 1 of the acceleration sensor is indicated by point 4. As the movable electrode 1 of the acceleration sensor is in an upper position, a capacitance is formed between the bottom surface of the movable electrode 1 and the top surface of the plate portion 2. The magnitude of the capacitance depends on the area

of the surfaces 1, 2 and the distance between the surfaces 1, 2. When the movable electrode 1 of the acceleration sensor moves to a lower position, the capacitance between the surfaces 1, 2 increases considerably, as the distance between the surfaces 1, 2 decreases.

The arrangements for supporting the movable electrode of the pair of electrodes and the structure of the electrodes of an acceleration sensor according to the present invention are described in more detail in the Applicant's co-pending patent application.

Summary of the Invention

The object of the present invention is to provide such an improved sensor structure, which achieves advantages of symmetry, and which enables reliable and efficient measuring of acceleration in particular in small capacitive acceleration sensor designs.

According to a first feature of the present invention there is provided a capacitive acceleration sensor comprising at least one pair of electrodes, such that each pair of electrodes comprises one movable electrode responsive to the acceleration and at least one stationary plate portion, such that each pair of electrodes further comprises an axis of rotation essentially forming a common axis, such that
- the movable electrode of the acceleration sensor is rigidly supported at the axis of rotation, such that the movable electrode is free to turn in a rotational motion about the axis of rotation, and that
- in the acceleration sensor a multitude of pairs of electrodes have been utilized.

Preferably, the locations of the pairs of electrodes are selected symmetrically in relation to axes of symmetry. Preferably, the shape of the electrodes of the pairs of electrodes are chosen to suit the number of pairs of electrodes. Preferably, in the acceleration sensor at least two pairs of electrodes are utilized.

Optionally two pairs of electrodes have been utilized in the acceleration sensor. Preferably, by using two pairs of electrodes, a one axis acceleration sensor has been implemented. Preferably, by using two pairs of electrodes a two axes acceleration sensor has been implemented. Preferably, the pairs of electrodes have been positioned such, that two axes of symmetry are formed. Preferably, the length of the line segment between the centers of gravity of each of the movable electrodes is shorter than the straight line drawn between any support points of different movable electrodes.

Preferably, three pairs of electrodes have been utilized in the acceleration sensor. Preferably, a one axis acceleration sensor has been implemented by using three pairs of electrodes. Alternatively, a two axes acceleration sensor has been implemented by using three pairs of electrodes. Alternatively, a three axes acceleration sensor has been implemented by using three pairs of electrodes. Preferably, the pairs of electrodes have been positioned such, that three axes of symmetry are formed. Preferably, the pairs of electrodes are located in the sensor such, that the angle between the positive direction vector of each movable electrode is 120° and 240° in relation to the positive direction vectors of the other two movable electrodes. Preferably, the negative direc-

tion vectors of the movable electrodes intersect essentially at a single point.

Alternatively, four pairs of electrodes are utilized in the acceleration sensor. Preferably, a one axis acceleration sensor has been implemented by using four pairs of electrodes. Alternatively, a two axes acceleration sensor has been implemented by using four pairs of electrodes. Alternatively, a three axes acceleration sensor has been implemented by using four pairs of electrodes. Preferably, the pairs of electrodes are positioned such, that four axes of symmetry are formed.

Preferably, the pairs of electrodes are located in the sensor such, that the angles between the positive direction vector of each movable electrode and the positive direction vectors of the other three movable electrodes are 90°, 180° and 270°. Preferably, the negative direction vectors of the movable electrodes intersect essentially at a single point.

Alternatively, eight pairs of electrodes are utilized in the acceleration sensor. Preferably, a one axis acceleration sensor has been implemented by using eight pairs of electrodes. Alternatively, a two axes acceleration sensor has been implemented by using eight pairs of electrodes.

Alternatively, a three axes acceleration sensor has been implemented by using eight pairs of electrodes. Preferably, the pairs of electrodes have been positioned such, that four axes of symmetry are formed. Preferably, the various pairs of electrodes have been adapted to measuring at different acceleration ranges. Preferably, some of the pairs of electrodes of the acceleration sensor are redundant pairs of electrodes. Preferably, some of the pairs of electrodes of the accelera-

tion sensor are used for linearisation of the capacitance change.

Brief Description of the Drawings

The present invention, and preferable methods of implementing it, are described in detail below, with exemplifying reference to the accompanying figures, of which:

Figure 1 shows a perspective view of the structure of a pair of electrodes of an acceleration sensor, according to prior art,

Figure 2 shows a side view of the functional structure of a pair of electrodes based on translatory motion of an acceleration sensor, according to prior art,

Figure 3 shows a side view of the functional structure of a pair of electrodes of an acceleration sensor, according to the present invention,

Figure 4 shows a perspective view of the structure of a pair of electrodes of an acceleration sensor, according to the present invention,

Figure 5 shows the change, expressed in percentages, in the capacitance of a pair of electrodes of an acceleration sensor, according to the present invention, as the distance between the surfaces of the pair of electrodes varies,

Figure 6 shows an acceleration sensor according to the present invention, implemented with two pairs of electrodes,

Figure 7 shows an acceleration sensor according to the present invention, implemented with three pairs of electrodes,

Figure 8 shows an acceleration sensor according to the present invention, implemented with four pairs of electrodes,

Figure 9 shows an acceleration sensor according to the present invention, implemented with eight pairs of electrodes,

Figure 10 shows an alternative acceleration sensor according to the present invention, implemented with four pairs of electrodes,

Figure 11 shows a second alternative acceleration sensor according to the present invention, implemented with four pairs of electrodes.

The Figures 1-2 are presented above. Below, the invention and preferable methods for its implementation are described with reference to the Figures 3-11.

Detailed Description of the Invention

Figure 3 shows a side view of the functional structure of a pair of electrodes of an acceleration sensor, according to the present invention. A pair of electrodes of the acceleration sensor according to the present invention comprises a movable electrode 5, a stationary electrode 6 and an axis of rotation 7.

The movable electrode 5 of the acceleration sensor is rigidly supported at the axis of rotation 7 such, that the movable electrode 5 is free to rotate in a rotational motion about

the axis of rotation 7. The movable electrode 5 in rotational motion constitutes that part of the acceleration sensor, which is responsive to acceleration, which part as a consequence of the acceleration performs rotational motion about the axis of rotation 7.

When, before the rotational motion, the movable electrode 5 of the acceleration sensor is in an upper position, a capacitance is formed between the bottom surface of the movable electrode 5 and the top surface of the stationary electrode 6. The magnitude of the capacitance depends on the area of the surfaces 5, 6, and on the distance between the surfaces 5, 6. When the movable electrode 5 of the acceleration sensor after the rotational motion rotates to a lower position, the capacitance between the surfaces 5, 6 increases, as the distance between the surfaces 5, 6 decreases.

The capacitance between the surfaces of the pair of electrodes of the acceleration sensor according to the present invention is unevenly distributed over the surfaces 5 and 6, since the distance between the surfaces 5, 6 varies. The acceleration sensor according to the present invention may also comprise a second pair of electrodes on the opposite side of the movable electrode 5.

In the acceleration sensor according to the present invention, the change in capacitance of the movable electrode in rotational motion is enhanced by means of the shape of the pair of electrodes in comparison with a pair of electrodes of rectangular shape. The increase in capacitance change is based on the unevenness in electrode distance caused by the rotational motion.

The position of the tip of the movable electrode in rotational motion is the factor, that limits the maximum value of the angle of rotation. Generally, there is a buffer structure on top of the stationary electrode, the pair of electrodes achieving its capacitance maximum, as the movable electrode hits that structure. The most sensitive area regarding the capacitance change is at the tip of the movable electrode, since that is where the distance of the pair of electrodes changes the most.

The maximum value of the angle of rotation depends on the maximum distance of the movable electrode from the axis of rotation, whereas the magnitude of the capacitance formed at the tip of the electrode depends on the width of the pair of electrodes. The capacitance of an unloaded pair of electrodes depends only on the surface of the pair of electrodes.

In the present invention, the pair of electrodes is shaped either by means of the movable electrode, the stationary electrode or both electrodes such, that a significant portion of the area of the pair of electrodes is as far away as possible from the axis of rotational motion at the stationary electrode. Shapes of pairs of electrodes according to the present invention are e.g. triangle-like, drop-like or hammer-like pairs of electrodes. With the structure according to the present invention the major part of the capacitance generated by the pair of electrodes is generated in the area, where the distance of the pair of electrodes changes greatly.

Figure 4 shows a perspective view of the structure of a pair of electrodes of an acceleration sensor according to the present invention. The pair of electrodes of the acceleration sensor according to the present invention comprises a

designed movable electrode 8, which moves according to the acceleration, and a designed stationary electrode 9. The movable electrode 8 constitutes that part 8 of the acceleration sensor, which is responsive to the acceleration, and which part, in consequence of the acceleration, moves in relation to the plate portion 9. The movable electrode 8 and the stationary electrode 9 form a pair of electrodes converting acceleration into an electrically measurable quantity, i.e. capacitance. In the Figure, the movable electrode 8 of the acceleration sensor is supported at points 10 and 11 of an axis of rotation.

Alternative shapes for the pairs of electrodes are, for example, triangle-like, drop-like or hammer-like pairs of electrodes. With a structure like this, the major part of the capacitance generated by the pair of electrodes is generated at the area, where the distance of the pair of electrodes changes greatly.

Figure 5 shows the change, expressed in percentages, in the capacitance of a pair of electrodes of an acceleration sensor according to the present invention, as the distance between the surfaces of the pair of electrodes varies. The horizontal axis shows the distance (d) between the surfaces of the pair of electrodes. Correspondingly, the vertical axis shows the change, expressed in percentages, in the capacitance of the pair of electrodes (%C change). The curve 12 depicts the change, expressed in percentages, in the capacitance of an ordinary pair of electrodes, having surfaces of rectangular shape moving in translatory motion, as the distance between the surfaces of the pair of electrodes varies. The curve 13, respectively, depicts the change, expressed in percentages, in the capacitance of a pair of electrodes with surfaces of

rectangular shape moving in rotational motion as the distance between the surfaces of the pair of electrodes varies.

Thus, it can be seen, that the change in capacitance of the pair of electrodes moving in a rotational motion, used in the measuring, is not equally large as in the case of the ordinary pair of electrodes with surfaces of rectangular shape moving in translatory motion. This change sensitivity needed for the measuring can be compensated by shaping the pair of electrodes. The curve 14 depicts the change, expressed in percentages, in the capacitance of a pair of electrodes with surfaces of triangular shape moving in rotational motion as the distance between the surfaces of the pair of electrodes varies.

The movable electrode of the pair of electrodes of the acceleration sensor according to the present invention has essentially two points of support with related springs providing a degree of freedom of rotation for the movable electrode about a straight line drawn through the points of support.

The movable electrodes can be limited to those having a direction of sensitivity to acceleration, which is not parallel to the electrode plane. Here, the electrode plane is understood to mean a plane of the electrode formed by the least squares method. Thus, the center of gravity of the movable electrode projected in a direction perpendicular to the electrode plane of the movable electrode onto a plane parallel to the electrode plane of the movable electrode, which plane parallel to the electrode plane of the movable electrode passes through the points of support of the movable electrode, said projected movable electrode must not lie on

the straight line drawn between the points of support of the movable electrode.

A multitude of pairs of electrodes can be used in the acceleration sensor according to the present invention. Thus, acceleration can be measured in relation to several different axes. The positioning of the pairs of electrodes is selected to be symmetrical in relation to an axis of symmetry, whereby the behavior of the pairs of electrodes, when subjected to temperature stress or other symmetrical load, will be equal.

The shape of the pairs of electrodes of the acceleration sensor is selected to suit the number of pairs of electrodes, whereby an optimal packing density is achieved by utilizing the shapes and positioning of the mass items. The support arrangements of the movable electrode of the pair of electrodes of the acceleration sensor according to the present invention and the structure of the electrodes are described in more detail in the Applicant's co-pending international patent application.

Figure 6 shows an acceleration sensor, according to the present invention, implemented with two pairs of electrodes. In the Figure, in addition to the triangular movable electrode, the axes of symmetry, the spring attachment points, the axis of rotation and the outer wall of the sensor are indicated. By using multiple pairs of electrodes and by suitably selecting the points of support, an acceleration sensor with alternatively one or two axes can be implemented. In the Figure, an acceleration sensor with two axes has been implemented using two pairs of electrodes. The pairs of electrodes are positioned such, that two axis of symmetry are obtained. In the acceleration sensor according to the present invention,

the center of gravity of each movable electrode and the length of the line segment between the centers of gravity must be shorter than the straight line drawn between any support points of the different movable electrodes.

Figure 7 shows an acceleration sensor, according to the present invention, implemented with three pairs of electrodes. In the Figure, in addition to the triangular movable electrode, the axes of symmetry, the spring attachment points, the axis of rotation and the outer wall of the sensor are indicated. By using multiple pairs of electrodes and by suitably selecting the points of support, an acceleration sensor with alternatively one, two or three axes can be implemented. In the Figure, an acceleration sensor with three axes has been implemented using three pairs of electrodes. The pairs of electrodes are positioned such, that three axis of symmetry are obtained. In the acceleration sensor according to the present invention, the positive direction is understood to be the direction from the support axis of the movable electrode towards the center of gravity, and the negative direction is understood to be the direction opposite to that. In the acceleration sensor according to the present invention, the pairs of electrodes are located in the sensor such, that the positive direction vector of each movable electrode is at an angle of 120°, and 240° in relation to the positive direction vector of the other two movable electrodes, and that the negative direction vectors of the movable electrodes intersect in essentially a single point.

Figure 8 shows an acceleration sensor, according to the present invention, implemented with four pairs of electrodes. In the Figure, in addition to the triangular movable electrode, the axes of symmetry, the spring attachment points, the axis

of rotation and the outer wall of the sensor are indicated. By using multiple pairs of electrodes and by suitably selecting the points of support, an acceleration sensor with alternatively one, two or three axes can be implemented. In the Figure, an acceleration sensor with three axes has been implemented using four pairs of electrodes. The pairs of electrodes are positioned such, that four axis of symmetry are obtained. In the acceleration sensor according to the present invention, the pairs of electrodes are located in the sensor such, that the positive direction vector of each movable electrode is at an angle of 90°, 180°, and 270° in relation to the positive direction vector of the other three movable electrodes, and that the negative direction vectors of the movable electrodes intersect in essentially a single point.

Figure 9 shows an acceleration sensor, according to the present invention, implemented with eight pairs of electrodes. In the Figure, in addition to the triangular movable electrode, the axes of symmetry, the spring attachment points, the axis of rotation and the outer wall of the sensor are indicated. By using multiple pairs of electrodes and by suitably selecting the points of support, an acceleration sensor with alternatively one, two or three axes can be implemented. In the Figure, an acceleration sensor with three axes has been implemented using eight pairs of electrodes. The pairs of electrodes are positioned such, that four axis of symmetry are obtained.

Different ranges of acceleration can be measured with the different pairs of electrodes of the acceleration sensor according to the present invention. Some pairs of electrodes of the acceleration sensor may also be redundant pairs of

electrodes. In addition, some of the pairs of electrodes of the acceleration sensor can be used for linearisation of the capacitance change.

Figure 10 shows an alternative acceleration sensor, according to the present invention, implemented with four pairs of electrodes. In the alternative acceleration sensor according to the present invention the pairs of electrodes are located in the sensor such, that the positive direction vector of each movable electrode is at an angle of 90°, 180°, and 270° in relation to the positive direction vector of the other three movable electrodes, and that the negative direction vectors of the movable electrodes intersect in essentially a single point in the center of the assembly. The electrode planes and support points of the movable electrodes are symmetrical in relation to four axes of symmetry in the electrode plane.

Figure 11 shows a second alternative acceleration sensor, according to the present invention, implemented with four pairs of electrodes. In the second alternative acceleration sensor according to the present invention, the pairs of electrodes are located in the sensor such, that the positive direction vector of each movable electrode is at an angle of 90°, 180°, and 270° in relation to the positive direction vector of the other three movable electrodes, and that the negative direction vectors of the movable electrodes intersect in essentially a single point in the center of the assembly. The electrode planes and support points of the movable electrodes are symmetrical in relation to four axes of symmetry in the electrode plane.

Advantages of symmetry are achieved with an acceleration sensor according to the present invention, and it enables reliable and efficient measuring of acceleration, in particular in small capacitive acceleration sensor designs.

Claims

1. A capacitive acceleration sensor comprising at least one pair of electrodes such, that each pair of electrodes comprises a movable electrode (5), which is responsive to the acceleration, and at least one stationary plate portion (6), **characterized** in, that each pair of electrodes further comprises an axis of rotation (7) essentially forming a common axis such, that

- the movable electrode (5) of the acceleration sensor is rigidly supported at the axis of rotation (7) such, that the movable electrode (5) is free to turn in a rotational motion about the axis of rotation (7), and that

- several pairs of electrodes are used in the acceleration sensor.

2. The capacitive acceleration sensor of Claim 1, **characterized** in, that the position of the pairs of electrodes is selected symmetrically in relation to axes of symmetry.

3. The capacitive acceleration sensor of Claim 1 or 2, **characterized** in, that the shape of the pairs of electrodes is selected to be suitable in relation to the number of pairs of electrodes.

4. The capacitive acceleration sensor of any one of the Claims 1-3 above, **characterized** in, that at least two pairs of electrodes are used in the acceleration sensor.

5. The capacitive acceleration sensor of any one of the Claims 1-3 above, **characterized** in, that two pairs of electrodes are used in the acceleration sensor.

6. The capacitive acceleration sensor of Claim 5, **characterized** in, that a one axis acceleration sensor is implemented by using two pairs of electrodes.

7. The capacitive acceleration sensor of Claim 5, **characterized** in, that a two axes acceleration sensor is implemented by using two pairs of electrodes.

8. The capacitive acceleration sensor of any one of the Claims 5-7 above, **characterized** in, that the pairs of electrodes are positioned such, that two axes of symmetry are formed.

9. The capacitive acceleration sensor of any one of the Claims 5-8 above, **characterized** in, that length of the line segment between the centers of gravity of each of the movable electrodes is shorter than the straight line drawn between any support points of different movable electrodes.

10. The capacitive acceleration sensor of any one of Claims 1-3 above, **characterized** in, that three pairs of electrodes are used in the acceleration sensor.

11. The capacitive acceleration sensor of Claim 10, **characterized** in, that a one axis acceleration sensor is implemented by using three pairs of electrodes.

12. The capacitive acceleration sensor of Claim 10, **characterized** in, that a two axes acceleration sensor is implemented by using three pairs of electrodes.

13. The capacitive acceleration sensor of Claim 10, **characterized** in, that a three axes acceleration sensor is implemented by using three pairs of electrodes.

14. The capacitive acceleration sensor of any one of the Claims 10-13 above, **characterized** in, that the pairs of electrodes are positioned such, that three axes of symmetry are formed.

15. The capacitive acceleration sensor of any one of the Claims 10-14 above, **characterized** in, that the pairs of electrodes are positioned in the sensor such, that the positive direction vector of each movable electrode is at an angle of 120°, and 240° in relation to the positive direction vector of the other two movable electrodes.

16. The capacitive acceleration sensor of any one of the Claims 8-15 above, **characterized** in, that the negative direction vectors of the movable electrodes intersect at essentially one point.

17. The capacitive acceleration sensor of any one of the Claims 1-3 above, **characterized** in, that four pairs of electrodes are used in the acceleration sensor.

18. The capacitive acceleration sensor of Claim 17, **characterized** in, that a one axis acceleration sensor is implemented by using four pairs of electrodes.

19. The capacitive acceleration sensor of Claim 17, **characterized** in, that a two axes acceleration sensor is implemented by using four pairs of electrodes.

20. The capacitive acceleration sensor of Claim 17, **characterized** in, that a three axes acceleration sensor is implemented by using four pairs of electrodes.

21. The capacitive acceleration sensor of any one of the Claims 17-20 above, **characterized** in, that the pairs of electrodes are positioned such, that four axes of symmetry are formed.

22. The capacitive acceleration sensor of any one of the Claims 17-21 above, **characterized** in, that the pairs of electrodes are positioned in the sensor such, that the positive direction vector of each movable electrode is at an angle of 90°, 180°, and 270° in relation to the positive direction vector of the other three movable electrodes.

23. The capacitive acceleration sensor of any one of the Claims 17-22 above, **characterized** in, that the negative direction vectors of the movable electrodes intersect at essentially one point.

24. The capacitive acceleration sensor of any one of the Claims 1-3 above, **characterized** in, that eight pairs of electrodes are used in the acceleration sensor.

25. The capacitive acceleration sensor of Claim 24, **characterized** in, that a one axis acceleration sensor is implemented by using eight pairs of electrodes.

26. The capacitive acceleration sensor of Claim 24, **characterized** in, that a two axes acceleration sensor is implemented by using eight pairs of electrodes.

27. The capacitive acceleration sensor of Claim 24, **characterized** in, that a three axes acceleration sensor is implemented by using eight pairs of electrodes.

28. The capacitive acceleration sensor of any one of the Claims 24-27 above, **characterized** in, that the pairs of electrodes are positioned such, that four axes of symmetry are formed.

29. The capacitive acceleration sensor of any one of the Claims 1-28 above, **characterized** in, that the different pairs of electrodes are adapted to measuring at different ranges of acceleration.

30. The capacitive acceleration sensor of any one of the Claims 1-29 above, **characterized** in, that some of the pairs of electrodes of the acceleration sensor are redundant pairs of electrodes.

31. The capacitive acceleration sensor of any one of the Claims 1-30 above, **characterized** in, that some of the pairs of electrodes of the acceleration sensor are used for linearisation of the change in capacitance.

Abstract

The invention relates to measuring devices used in the measurement of acceleration and, more specifically, to capacitive acceleration sensors. The capacitive acceleration sensor according to the present invention contains a movable electrode (5) of the acceleration sensor supported at an axis of rotation (7). Several pairs of electrodes are utilized in the acceleration sensor according to the present invention. Advantages of symmetry are achieved with the acceleration sensor structure according to the present invention, and it enables reliable and efficient measuring of acceleration, in particular in small capacitive acceleration sensor designs.

(Figure 3)

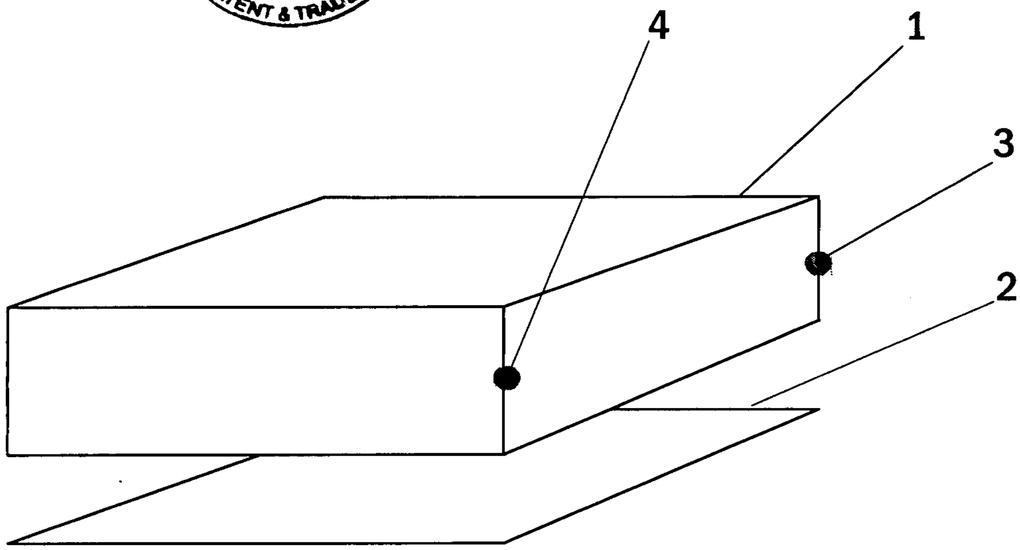

Fig. 1

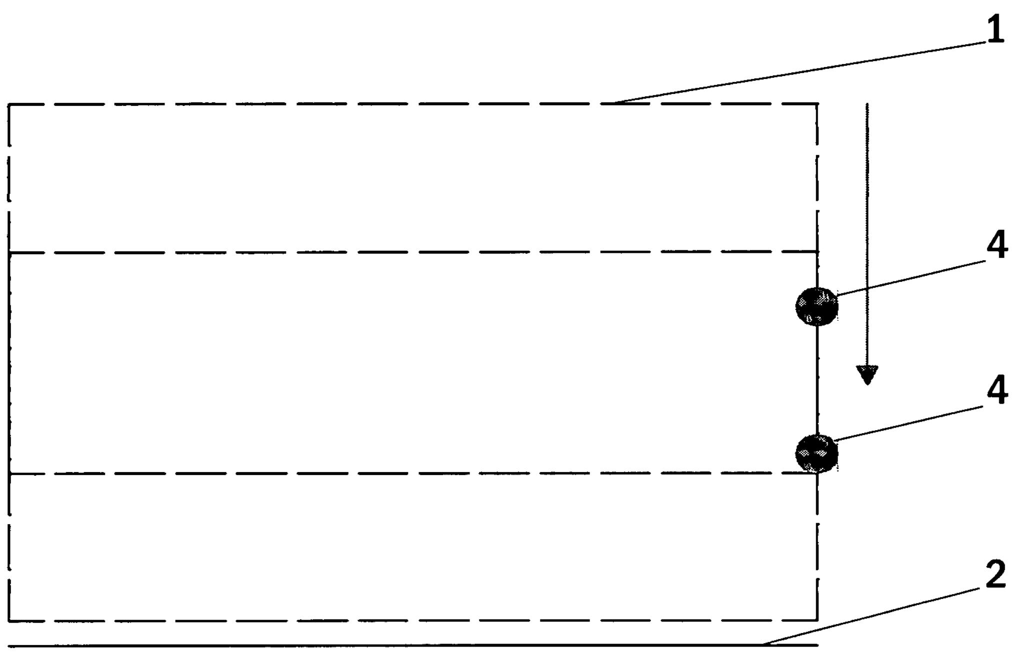

Fig. 2

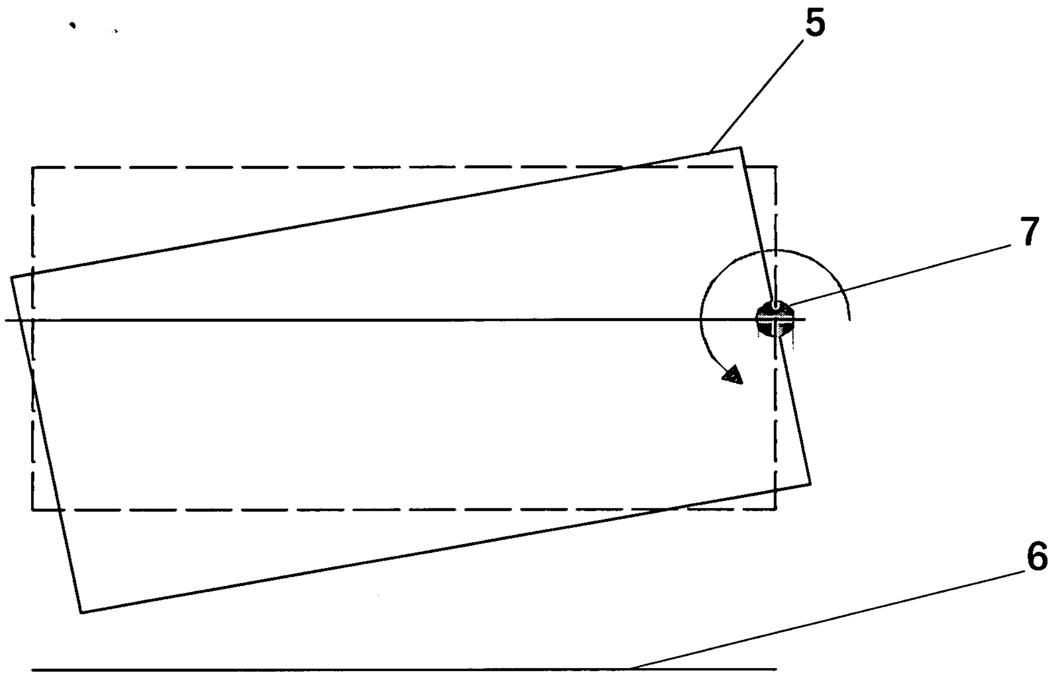

Fig. 3

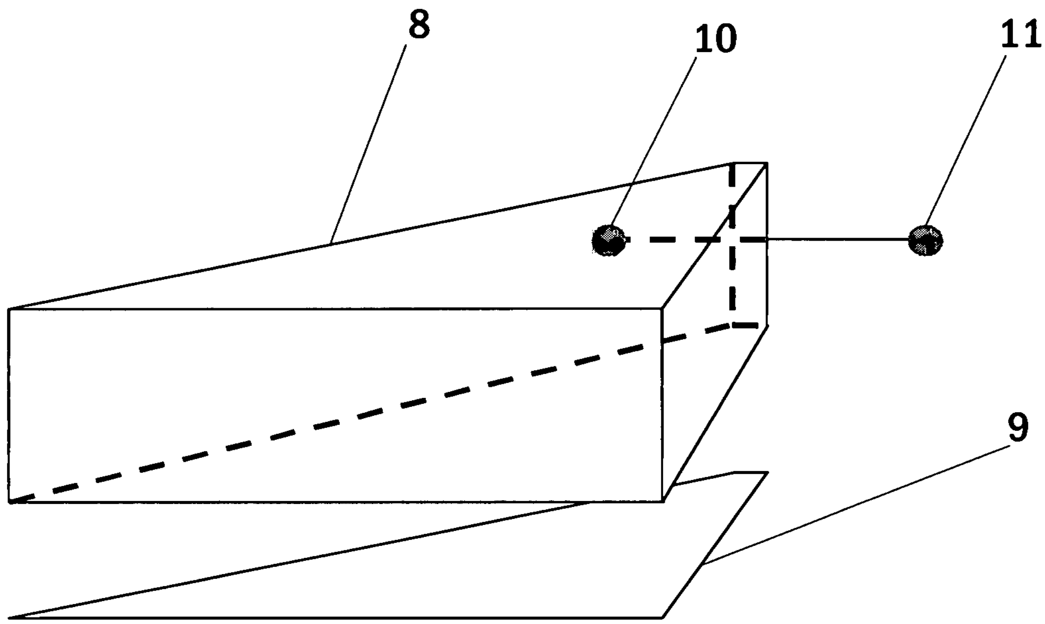

Fig. 4

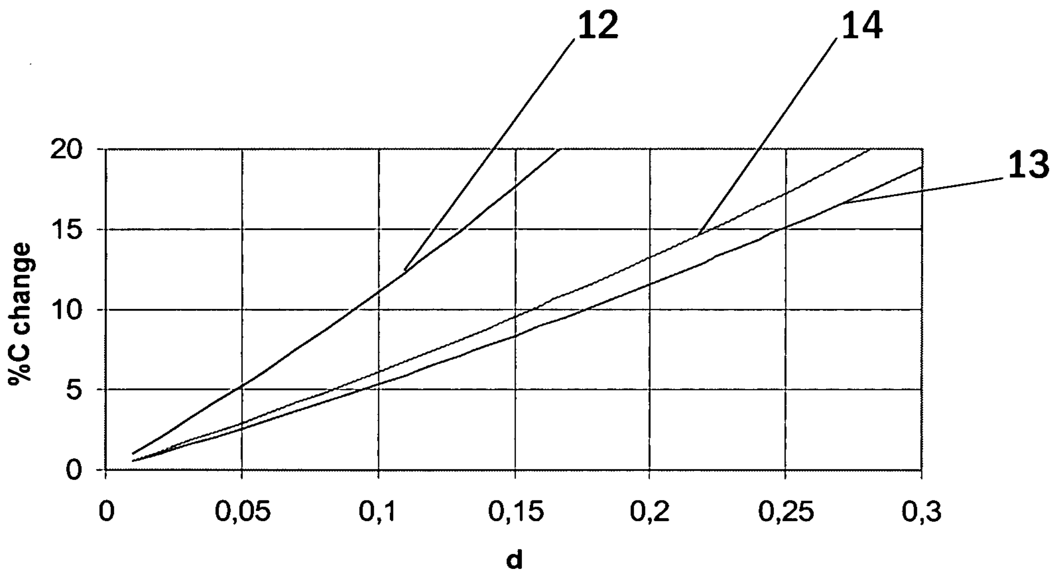

Fig. 5

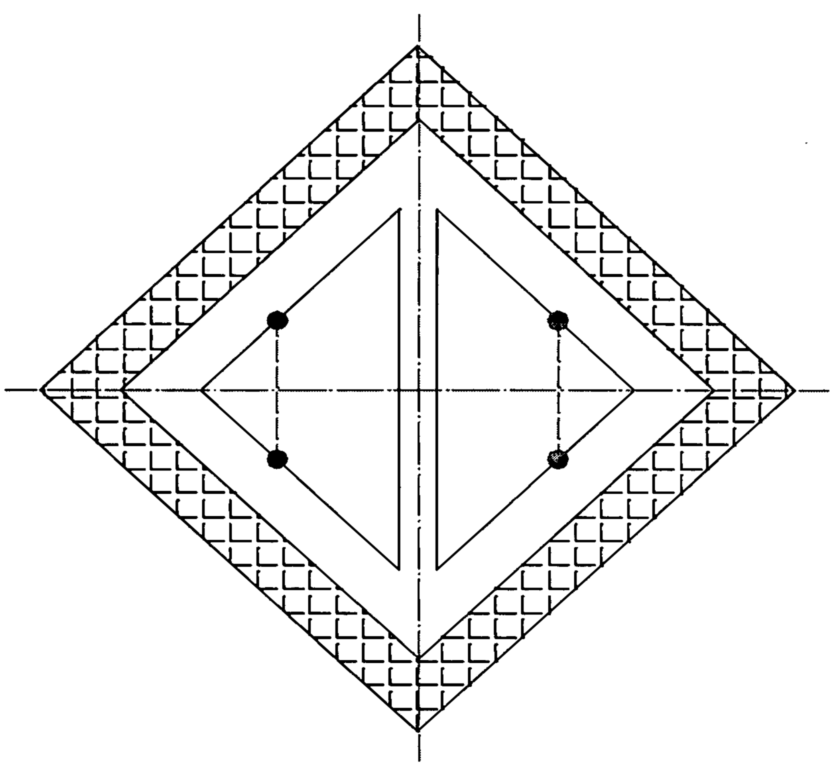

Fig. 6

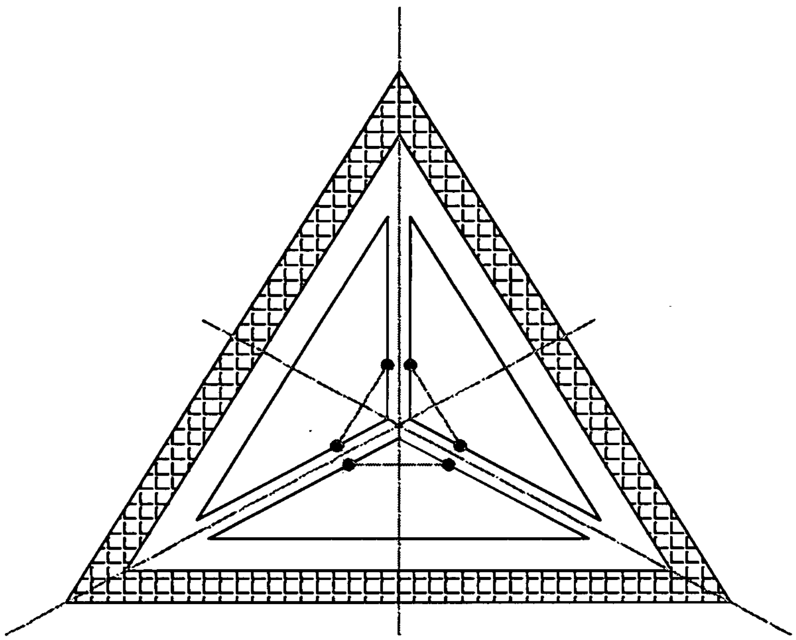

Fig. 7

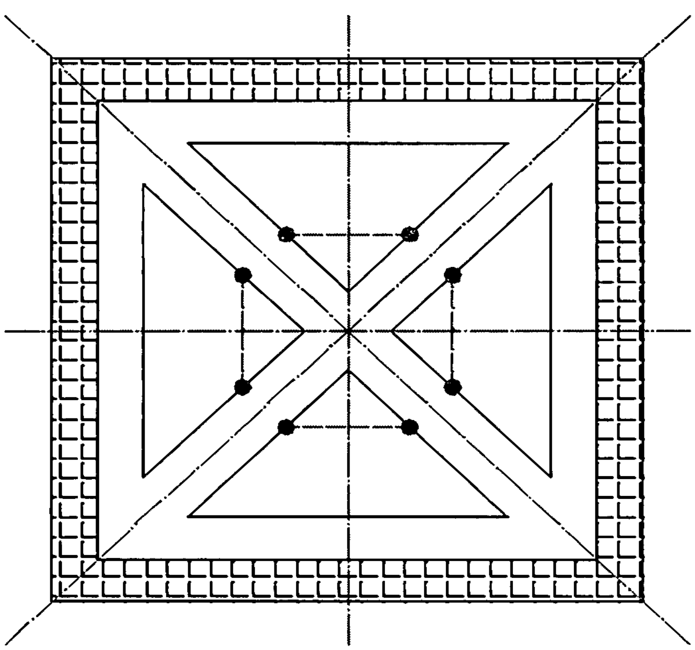

Fig. 8

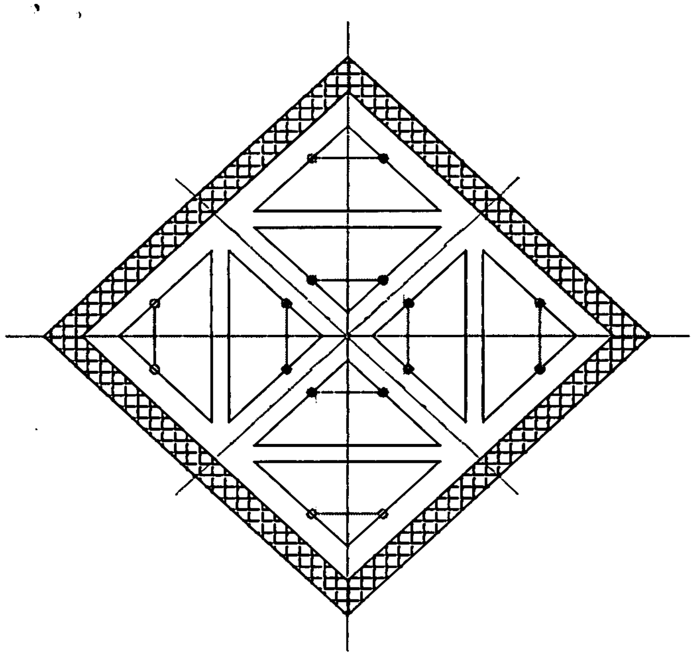

Fig. 9

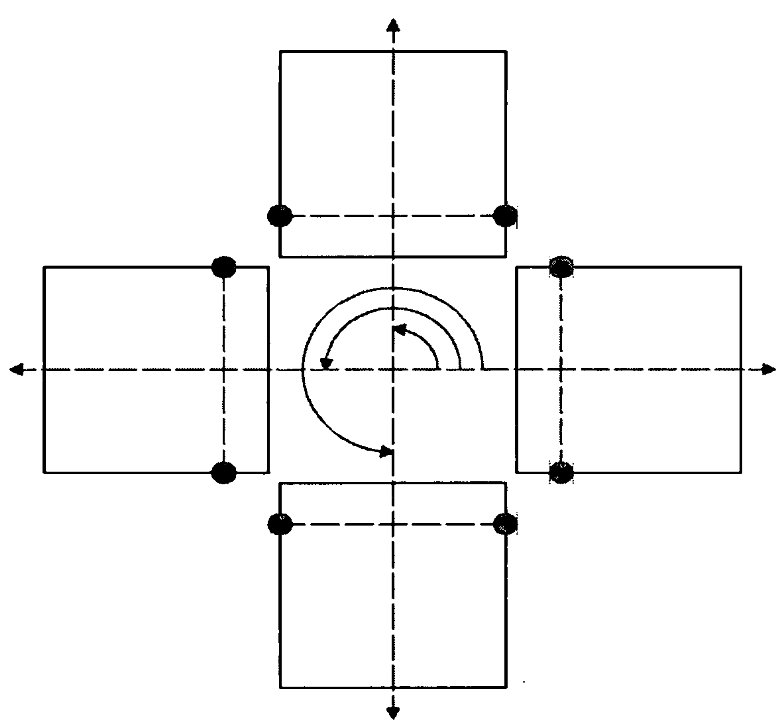

Fig. 10

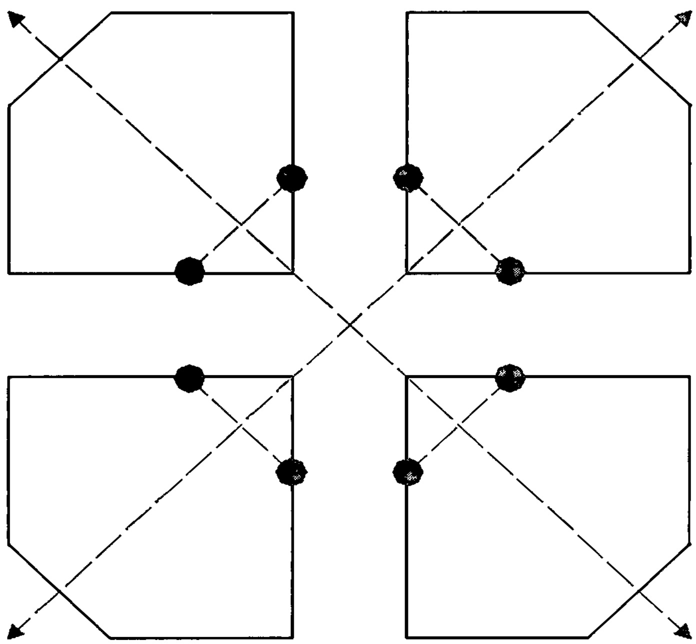

Fig. 11